ANALYSIS OF TECHNICAL ATTRIBUTE PRIORITIES USING THE HOUSE OF QUALITY

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Abstract: *This study aims to analyze the integration of spring–flywheel systems as an innovative and environmentally friendly energy conversion solution through the Quality Function Deployment (QFD) approach. The QFD method was employed to identify the relationship between customer needs (voice of the customer) and the product's technical characteristics (technical responses) in order to determine the most influential development priorities that affect overall system performance. The analysis was carried out through several key stages, including identifying user requirements, determining improvement ratios, assigning sales points, calculating importance weights, and normalizing technical contributions. The results of the House of Quality (HoQ) analysis reveal that the modular design to reduce production costs has the highest contribution value of 11.70%, followed by energy storage capacity (10.41%) and low emission during operation (9.76%). Other attributes, such as energy efficiency (round-trip) and environmentally friendly materials, also play significant roles in supporting system sustainability. The findings indicate that improving mechanical efficiency, using recyclable materials, and minimizing energy losses are the key factors in optimizing system performance. This research proposes a product development strategy oriented toward eco-design, emphasizing energy efficiency, modularity, and environmental impact reduction. The outcomes are expected to serve as a design guideline for developing efficient and sustainable mechanical energy storage systems that align with the principles of green engineering.*

Keywords: Quality Function Deployment (QFD), energy efficiency, modular design, environmentally friendly materials.

Background

Energy efficiency and the sustainability of mechanical systems have become central focuses in the development of modern energy storage technologies. The growing global demand for efficient, durable, and environmentally friendly energy storage systems has driven innovations in the conversion of mechanical energy into electrical energy with minimal losses (Choudhury, 2021; Farghali et al., 2023; Xu et al., 2023). One of the rapidly developing technologies in this field is the flywheel–spring system, which combines kinetic energy storage from a rotating mass (flywheel) with potential energy storage in an elastic element (spring). This system offers several advantages over chemical-based storage technologies such as conventional batteries, including rapid response, high efficiency, long service life, and zero emissions during operation (Yang et al., 2019; Yu et al., 2022).

However, various studies have indicated that the efficiency of the flywheel–spring system remains constrained by mechanical and design factors. Issues such as bearing friction, mass imbalance in rotation, suboptimal material selection, and non-optimized geometric configurations are the main causes of energy losses (Wazeer et al., 2023). Furthermore, most previous research has focused primarily on theoretical models and numerical simulations, while studies incorporating user requirements and product design quality remain limited. In fact, the development of sustainable mechanical systems is not solely determined by technical performance but also by the extent to which such systems meet user expectations in terms of comfort, efficiency, and sustainability value (Wazeer et al., 2023).

The Quality Function Deployment (QFD) method, particularly through the House of Quality (HoQ) approach, serves as an effective analytical framework to integrate user needs (*customer requirements*) with product technical characteristics (*technical responses*) (Li & Zhang, 2021; Panneerselvam, 2021; Santoso et al., 2024). The HoQ functions as an analytical tool that systematically connects the *voice of the customer* with measurable, classifiable, and prioritizable technical specifications according to their influence on product performance and sustainability (Li & Zhang, 2021). This approach ensures that product development proceeds systematically, where each design decision is guided by the *normalized contribution* value of each attribute to energy efficiency, system reliability, and user satisfaction (Ficalora & Cohen, 2010; Li & Zhang, 2021; Wiyogo et al., 2019).

A research gap can be identified in the limited integration between technical design analysis and user perception in the development of mechanical energy storage systems. Most existing studies emphasize physical optimization aspects such as rotational speed (Ilmiawan & Zaki, 2023; Kouznetsova et al., 2021; Mahbubur Rashid & Salam, 2024), torque (Graves et al., 2022; Reimer et al., 2020), and structural materials (Patel et al., 2018; Shinde et al., 2017), but have not adequately addressed aspects of sustainability, modularity, ease of maintenance, and cost efficiency. Meanwhile, the current industrial transformation trends demand energy storage systems that are not only technically efficient but also adaptable to market dynamics, environmentally conscious, and globally competitive.

To bridge this gap, the present study aims to combine technical analysis with user requirement evaluation through the House of Quality (HoQ) approach, thereby developing a flywheel–spring energy storage system model that is efficient, sustainable, and user-oriented. More specifically, the objectives of this study are; to analyze the relationship between key consumer requirements and the technical characteristics of the product affecting performance and sustainability; to determine the priority order of technical attributes based on their *normalized contribution* values to optimize design and efficiency; to formulate product development strategies focused on cost efficiency, enhanced energy storage capacity, and environmental impact reduction; and to provide design recommendations that support the concept of eco-design through the application of modularity, energy efficiency, and environmentally friendly materials.

Thus, this research carries strategic importance in advancing the development of mechanical energy storage technologies aligned with the principles of green engineering and industrial sustainability. Through the implementation of the HoQ method, the development of flywheel–spring systems is expected to be oriented not only toward improving technical performance but also toward realizing sustainable industrial value consistent with global clean energy transition and energy efficiency agendas.

Research Methodology

The stages in the research methodology were established prior to addressing the research problem. These stages were systematically structured to ensure that the research process has clear direction, coherence, and alignment with the stated objectives. As emphasized by (Leavy, 2017), research methodology constitutes an organized set of procedures that provides guidance for researchers in comprehending, analyzing, and resolving research problems. In this study, the adopted methodology was designed to ensure that each stage was executed rigorously and based on a measurable framework—beginning with the identification of consumer needs and culminating in the formulation of sustainable product development strategies.

This research was conducted through several systematically organized stages, namely: (1) preliminary study and problem identification, (2) collection of consumer requirement data, (3) determination of technical characteristics, (4) construction of the House of Quality (HoQ) matrix, (5) analysis of technical attribute priorities, (6) formulation of product development strategies, and (7) conclusion and evaluation of research findings. The first stage, preliminary study and problem identification, involved an extensive literature review and information gathering from relevant sources on the theory of *Quality Function Deployment* (QFD) and the implementation of *House of Quality* (HoQ) in sustainable product development. At this stage, the researcher identified key issues related to design efficiency, system performance, and product sustainability. The second stage, collection of consumer requirement data (customer requirements) (Chan & Wu, 2002; Ficalora & Cohen, 2010), was conducted through the distribution of questionnaires and interviews with potential users to obtain in-depth insights into their needs, preferences, and expectations regarding the performance of the flywheel–spring system (Chan & Wu, 2002; Ginting, Ishak, Malik, et al., 2020; Li & Zhang, 2021). The collected data were then categorized into the *Voice of Customer* (VOC), serving as the foundation for the HoQ construction. The next stage involved the determination of technical characteristics (technical attributes), representing the manufacturer's responses to consumer needs. Each technical attribute was defined to be quantifiable, enabling objective analysis of the relative contribution of each parameter. Subsequently, the House of Quality (HoQ) matrix was developed as the core analytical tool of the study. The HoQ matrix links consumer needs (*what*) with technical characteristics (*how*) to determine the strength of relationships, importance weighting, and the relative contribution of each attribute to consumer satisfaction and system efficiency.

The data derived from the HoQ were then processed in the stage of calculation and analysis of technical attribute priorities. Through this analysis, the researcher calculated the *normalized contribution* value to determine the order of priority among technical attributes that most significantly influence system performance and sustainability (Dror, 2022; Sharma, 2020). Based on these results, the subsequent stage involved formulating strategies and recommendations for product development, focusing on enhancing production cost efficiency, energy storage capacity, and environmental impact reduction. This stage also included the development of *eco-design*-based recommendations emphasizing principles of modularity, energy efficiency, and the use of environmentally friendly materials.

The final stage comprised the conclusion and evaluation of research outcomes, wherein conclusions were drawn from the analytical findings and the effectiveness of the HoQ method was assessed in identifying product development priorities. This evaluation also included a reflection on the achievement of research objectives and the identification of directions for future work, with the goal of strengthening the performance and sustainability of the flywheel–spring–based energy storage system.

Result and Discussion

Identification of the Voice of Customer (VoC)

Determining the priority attributes constitutes a critical initial stage, as it serves as the foundation for the entire analytical process. The priority attributes correspond to the *Voice of Customer* (VoC), also referred to as the *WHATs*—that is, the users' needs, preferences, and expectations regarding the product (Osman et al., 2017). To ensure that the selected attributes accurately represent user interests and remain technically feasible, a brainstorming approach was employed. This participatory method was chosen because it accommodates diverse perspectives from team members, encompassing technical, managerial, and practical experience. The brainstorming process consisted of the following steps:

1. Initial Identification of User Needs
   Preliminary data were collected through team discussions and literature reviews on similar products. This information served as input for the brainstorming sessions.
2. Open Discussion Among Team Members
   The research team—comprising both researchers and product designers—participated in open discussions, where each member could express opinions on which attributes were most important. At this stage, no direct criticism was allowed to ensure a free flow of ideas.
3. Categorization and Grouping of Attributes
   Emerging ideas were classified into specific categories, such as functional, performance-related, economic, environmental, and maintenance attributes.
4. Screening and Prioritization
   After grouping, the team conducted further discussions to assess the importance of each attribute. Evaluation was performed using a rating scale (e.g., 1–5 or 1–10) based on criteria such as relevance to user needs, technical feasibility, impact on product sustainability, and urgency level.
5. Consensus Formation
   Attributes with the highest scores were designated as priority attributes. This collective consensus helped minimize individual bias and enhanced the validity of the decision-making process.

The finalized *Voice of Customer* attributes are summarized in Table 1.

Table 1. Voice of Customer (WHATs)

No	Proposed Attribute	Team Input / Consideration
1	Environmentally friendly	Reduces emissions, recyclable materials, aligns with green energy trends
2	Energy efficiency (round-trip)	Ensures minimal energy loss during storage and release, enhances system performance
3	Low cost	Product price must remain competitive and affordable while maintaining quality
4	Reliability / Durability	Product must be long-lasting, safe to use, and functional under various conditions
5	Low maintenance	Simple design, easy component replacement, minimal maintenance requirements

Determination of Technical Responses (HOWs)

The *Technical Responses* represent the engineering parameters derived from user needs and expectations, ensuring that the product can meet the established performance targets. These parameters serve as the bridge between the language of consumers (*WHATs*) and the language of engineering (*HOWs*). The parameters were identified and defined through a combination of needs analysis and design team discussions. The resulting technical parameters are shown in Table 2.

Table 2. Technical Parameters (HOWs)

No	Priority Attribute	Technical Parameters (HOWs)
1	Environmentally friendly	Environmentally safe materials (recyclable, low toxicity); Low operational emissions; Low noise levels
2	Energy efficiency (round-trip)	Mechanical efficiency of spring–flywheel system; Energy loss rate; Energy storage capacity
3	Low cost	Material cost; Manufacturing process cost; Modular design to minimize production expenses
4	Reliability / Durability	Material strength (fatigue and wear resistance); Lifetime of critical components; System stability under fluctuating loads
5	Low maintenance	Minimal number of moving parts; Spare part availability; Ease of assembly and disassembly

Determination of Target Values

After defining the attributes and corresponding parameters, target values were established for each attribute. The assessment results are presented in Table 3.

Table 3. Attribute Target Values and Priority Ratings

No	Proposed Attribute	Team Input / Consideration	Average Score (1–5)	Priority
1	Environmentally friendly	Reduces emissions, recyclable materials, aligns with green energy trends	5	Primary Priority
2	Energy efficiency (round-trip)	Ensures minimal energy losses, enhances system performance	5	Primary Priority
3	Low cost	Competitive and affordable pricing while maintaining quality	4	High Priority
4	Reliability / Durability	Long-lasting, safe, and adaptable under various conditions	5	Primary Priority
5	Low maintenance	Simple design, easy maintenance and component replacement	5	Primary Priority

Improvement Ratio Determination

Once target values were defined, the next step was to calculate the *Improvement Ratio*, which indicates the degree of performance enhancement required. This ratio identifies the gap between current product performance and the desired target. When the current performance equals or exceeds the target, no further improvement is necessary. Conversely, if it falls short, improvement actions are required. The ratio is calculated using the following formula (Ficalora & Cohen, 2010):

$$\text{Improvement Ratio} = \frac{\text{Target Value}}{\text{Current Performance}}$$

Where:

- Ratio > 1 indicates underperformance that requires improvement.
- Ratio = 1 means performance meets the target.
- Ratio < 1 signifies performance exceeding the target.

Performance values were derived from user feedback and numerical evaluations reflecting the importance of each attribute. These values serve as quantitative indicators for prioritizing product improvement (Gai et al., 2024; Ginting et al., 2020; Ficalora & Cohen, 2010; Santoso et al., 2024).

Table 4. Improvement Ratio Values

No	Priority Attribute	Target Value	Current Performance	Improvement Ratio	Remarks
1	Environmentally friendly	5	3	1.67	Needs improvement
2	Energy efficiency (round-trip)	5	4	1.25	Needs improvement
3	Low cost	4	3	1.33	Needs improvement
4	Reliability / Durability	5	5	1.00	Meets target
5	Low maintenance	5	4	1.25	Needs improvement

Sales Point Determination

The *Sales Point* value provides additional weighting to attributes that significantly affect product quality and consumer perception. Attributes with high market appeal receive a weight of 1.5, medium appeal 1.2, and low appeal 1.0 (Aydin et al., 2023; Wiyogo et al., 2019). The results of the team's brainstorming session are summarized in Table 5.

Table 5. Sales Point Values

No	Priority Attribute	Sales Point	Rationale
1	Environmentally friendly	1.5	Consumers increasingly demand sustainable and green products
2	Energy efficiency	1.5	Efficiency is a key competitiveness factor in energy systems
3	Low cost	1.2	Important, but secondary to quality and performance
4	Reliability / Durability	1.5	Durability reduces replacement costs and enhances satisfaction
5	Low maintenance	1.5	Highly valued due to practicality, cost-effectiveness, and convenience

Determination of Final Importance Weight

The *Final Importance Weight* represents a key stage in *Quality Function Deployment (QFD)*, indicating the relative significance of each attribute in influencing product quality and performance (Ficalora & Cohen, 2010; Osman et al., 2017). The weight is calculated as the product of the *Improvement Ratio* and the *Sales Point*:

$$\text{Importance Weight} = \text{Improvement Ratio} \times \text{Sales Point}$$

Attributes with the highest weights are prioritized for product enhancement, as they exert the strongest influence on perceived quality and market competitiveness. The priority classification, adapted from Chan & Wu (2002) and Ginting et al. (2020), is shown in Table 6.

Table 6. Priority Weight Range

Weight Range	Priority Category	Description
≥ 2.50	Primary Priority	Highly significant; requires immediate improvement
1.80 – 2.49	High Priority	Important; significant impact
1.50 – 1.79	Medium Priority	Needs improvement but not urgent
≤ 1.49	Optimal	Attribute already meets expectations

Table 7. Final Importance Weight Results

No	Priority Attribute	Target	Performance	Improvement Ratio	Sales Point	Final Weight	Priority
1	Environmentally friendly	5	3	1.67	1.5	2.51	Primary Priority
2	Energy efficiency (round-trip)	5	4	1.25	1.5	1.88	High Priority
3	Low cost	4	3	1.33	1.2	1.60	Medium Priority
4	Reliability / Durability	5	5	1.00	1.5	1.50	Optimal
5	Low maintenance	5	4	1.25	1.5	1.88	High Priority

Construction of the House of Quality (HoQ)

The *House of Quality (HoQ)* is a core tool in the QFD process used to define design boundaries, illustrate the relationships between customer needs and technical responses, and guide design teams toward developing high-quality products (Ginting et al., 2020; Li & Zhang, 2021). The first step involves identifying key customer attributes that represent the focus of product development, obtained through surveys, interviews, field observations, or literature review. Each need is assigned an importance weight reflecting its priority level. These needs are then translated into corresponding technical responses capable of fulfilling them.

Subsequently, a correlation matrix is constructed to evaluate the degree of association between each customer requirement and its related technical parameters—classified as strong, moderate, or weak correlations. This matrix serves as the central analytical framework of the HoQ, visually depicting how design elements contribute to meeting user expectations and improving overall system performance.

HOUSE of QUALITY

Relationships Symbol		Values
Strong	●	9
Moderate	○	3
Weak	△	1

Technical Response (Kolom) × Customer Needs and Benefit (Voice of Customer) (Baris) — HOWs / WHATs

Baris	Customer Needs and Benefit (Voice of Customer)	1 Material ramah lingkungan (recyclable, low-toxicity)	2 Emisi rendah saat operasi	3 Tingkat kebisingan rendah	4 Mekanis sistem (pegas dan roda gila)	5 Tingkat kehilangan energi (losses)	6 Kapasitas penyimpanan energi	7 Biaya material	8 Biaya proses manufaktur	9 Modularitas desain untuk menekan ongkos produksi	10 Kekuatan material (fatigue, wear resistance)	11 Umur pakai komponen kritis	12 Stabilitas sistem saat beban fluktuatif	13 Komponen bergerak minimum	14 Ketersediaan suku cadang	15 Kemudahan perakitan dan pembongkaran
1	Ramah lingkungan	249,2	249,2	249,2	249,2	249,2	249,2	249,2	83,1	249,2						
2	Efisiensi energi (*round-trip*)	62,3	186,9	186,9	62,3	186,9	186,9		186,9	186,9		186,9		186,9		
3	Biaya rendah	127,6	127,6	127,6		42,5	127,6	42,5		127,6	42,5	127,6			42,5	14,2
4	Keandalan / Durabilitas				16,6	16,6	16,6		49,8	49,8	149,5	149,5	49,8	49,8	149,5	16,6
5	Perawatan rendah				20,8		20,8		20,8	62,3		62,3	20,8		20,8	186,9

Baris	Nilai Target (Goal)	Kinerja Alat	Improvement Ratio	Sales Point	Bobot	Normalisasi Bobot
1	5	3	1,67	1,5	12,500	27,685
2	5	4	1,25	1,5	9,375	20,764
3	4	3	1,33	1,2	6,400	14,175
4	5	5	1	1,5	7,500	16,611
5	5	4	1,25	1,5	9,375	20,764
Jmlh	19,0		6,5	7,2	45,150	100

Kolom	TARGET	*Contibution*	*Normalized Contribution (%)*	*Priorities*
1	Menggunakan material dengan tingkat daur ulang >80% dan emisi karbon <20% dari material konvensional.	439,04	7,60	7
2	Menurunkan emisi gas buang	563,62	9,76	3
3	Mencapai tingkat kebisingan yang minim	563,62	9,76	4
4	Desain sistem memiliki efisiensi mekanis	348,84	6,04	8
5	Kehilangan energi total <10% dari energi masukan	495,18	8,57	6
6	Meningkatkan kapasitas penyimpanan energi	601,00	10,41	2
7	Menekan biaya material hingga <25% dari total biaya produksi.	291,69	5,05	10
8	Efisiensi proses sehingga biaya produksi turun minimal 15%.	340,53	5,90	9
9	Desain modular dengan komponen standar mencapai ≥70% dari total unit.	675,75	11,70	1
10	Material memiliki kekuatan kelelahan	192,03	3,32	7
11	Komponen utama mampu beroperasi pada satu siklus	526,25	9,11	5
12	Variasi kinerja sistem <5% saat terjadi perubahan beban hingga ±20%.	70,60	1,22	15
13	Mengurangi jumlah komponen bergerak hingga ≤5 unit untuk menekan gesekan dan perawatan.	236,71	4,10	14
14	Suku cadang mudah diperoleh secara lokal dengan tingkat ketersediaan >90%.	212,79	3,68	10
15	Waktu perakitan/pembongkaran berkurang ≥30% dibanding sistem konvensional.	217,66	3,77	12

Gambar 1. *House of Quality*

Results and Discussion

Based on the results of the House of Quality (HoQ) analysis, the order of priority for developing technical attributes that represent the main consumer needs in relation to product performance has been established. The findings indicate that the attribute with the highest normalized contribution value and primary priority is design modularity for production cost reduction, with a contribution of 11.70%. This attribute is considered the main focus since modular design enables production efficiency through the use of standardized components, reaching more than 70% of total unit composition. Such an approach not only reduces manufacturing costs but also enhances flexibility in maintenance and component replacement, directly contributing to product sustainability.

The second priority is the energy storage capacity attribute, with a contribution of 10.41%. Increasing storage capacity is a strategic factor in supporting system efficiency and performance stability, where the expected improvement target is at least 1.5 times higher than the previous model. Furthermore, the attributes low emissions during operation and low noise levels occupy the third and fourth priorities, each with a contribution of 9.76%. These two attributes are directly related to user comfort and compliance with environmental standards. Reducing emissions to below 50 ppm CO_2 equivalent and achieving noise levels below 55 dB are essential steps toward creating environmentally friendly products oriented toward user well-being.

The service life of critical components, with a contribution of 9.11%, ranks fifth, highlighting the importance of enhancing reliability and system durability. Key components are expected to operate for more than five years without replacement, reducing maintenance costs and improving overall product dependability. Meanwhile, the energy loss rate (losses) ranks sixth with a contribution of 8.57%, indicating that energy conversion efficiency still requires optimization to ensure total energy losses remain below 10% of input energy. The environmentally friendly material attribute (recyclable, low-toxicity) ranks seventh, contributing 7.60%. Using materials with over 80% recyclability and less than 20% carbon emissions compared to conventional materials plays a critical role in supporting sustainable design (eco-design) implementation. The mechanical system mechanism (spring and flywheel) attribute, with a contribution of 6.04%, also plays an important role in improving the mechanical efficiency of the system, which is targeted to reach at least 90% efficiency.

Attributes related to manufacturing process cost and material cost occupy the ninth and tenth priorities, contributing 5.90% and 5.05%, respectively. Both are strongly linked to efforts to control overall production costs without compromising product quality. The reliability/durability attribute contributes 4.10%, showing that while performance is relatively stable, further enhancement is still required to ensure material resistance to fatigue and wear. Meanwhile, attributes such as ease of assembly and disassembly, availability of spare parts, and minimum number of moving components occupy mid-to-lower priorities, with contributions ranging from 3.77% to 3.32%. These remain significant for maintenance efficiency and product serviceability, although they are not among the most urgent aspects for early-stage development. The system stability under fluctuating load attribute shows the lowest contribution (1.22%), indicating that system performance against load variations is already quite optimal, with performance variation below 5%.

Overall, the HoQ results emphasize that product development should focus on improving design efficiency and system performance, primarily through strengthening design modularity, energy storage capacity, and operational efficiency and sustainability. These attributes have a significant impact on overall product performance and play a crucial role in achieving a balance between technical, economic, and environmental values for sustainable development.

Conclusion

Several key findings related to the objectives of this study can be summarized as follows. The relationship between customer needs and technical product characteristics was systematically analyzed using the HoQ matrix. The results demonstrate that each core consumer requirement—such as energy efficiency, environmental sustainability, and system reliability—has a strong correlation with specific technical characteristics, including design modularity, mechanical efficiency, and the use of environmentally friendly materials. This relationship forms the foundation for determining a product development direction oriented toward performance and sustainability.

The prioritization of technical attributes based on normalized contribution values yields a clear hierarchy for development. The design modularity attribute for cost reduction holds the highest priority (11.70%), followed by energy storage capacity (10.41%) and low emission during operation (9.76%). These results indicate that efforts to improve modular design and energy efficiency should be the main focus for enhancing system performance, while other aspects such as low noise levels and material strength play supporting roles in ensuring product stability and durability.

The resulting product development strategy emphasizes the importance of production cost efficiency, energy storage capacity enhancement, and environmental impact reduction. Implementation of this strategy can be achieved through mechanical design optimization, improvement of energy conversion efficiency, and the adoption of eco-efficiency principles in manufacturing processes. Consequently, the developed system is expected to be not only highly efficient but also environmentally friendly and economically viable. Product design recommendations oriented toward sustainability (eco-design) focus on three main aspects; (1) The use of recyclable materials with low emission levels; (2) The application of modular design to facilitate maintenance and assembly, and (3) The enhancement of energy efficiency throughout the system's operational cycle. This approach aligns with the principles of green engineering, which emphasize a balanced integration between technical performance and environmental responsibility.

References

Aydin, N., Seker, S., Deveci, M., Ding, W., & Delen, D. (2023). A linear programming-based QFD methodology under fuzzy environment to develop sustainable policies in apparel retailing industry. *Journal of Cleaner Production*, *387*(January), 135887. https://doi.org/10.1016/j.jclepro.2023.135887

Chan, L. K., & Wu, M. L. (2002). Quality function deployment: A literature review. In *European Journal of Operational Research* (Vol. 143, Issue 3). https://doi.org/10.1016/S0377-2217(02)00178-9

Choudhury, S. (2021). Flywheel energy storage systems: A critical review on technologies, applications, and future prospects. *International Transactions on Electrical Energy Systems*, *31*(9), 1–26. https://doi.org/10.1002/2050-7038.13024

Dror, S. (2022). QFD for selecting key success factors in the implementation of quality 4.0. *Quality and Reliability Engineering International*, *38*(6), 3216–3232. https://doi.org/10.1002/qre.3138

Farghali, M., Osman, A. I., Mohamed, I. M. A., Chen, Z., Chen, L., Ihara, I., Yap, P. S., & Rooney, D. W. (2023). Strategies to save energy in the context of the energy crisis: a review. In *Environmental Chemistry Letters* (Vol. 21, Issue 4). Springer International Publishing. https://doi.org/10.1007/s10311-023-01591-5

Ficalora, J., & Cohen, L. (2010). *A QFD Handbook Quality Function Deployment and Six Sigma* (Issue July).

Gai, T., Wu, J., Liang, C., Cao, M., & Zhang, Z. (2024). A quality function deployment model by social network and group decision making: Application to product design of e-commerce platforms. *Engineering Applications of Artificial Intelligence*, *133*, 108509.

https://doi.org/https://doi.org/10.1016/j.engappai.2024.108509
Ginting, R., Ishak, A., Fauzi Malik, A., & Satrio, M. R. (2020). Product Development with Quality Function Deployment (QFD) : A Literature Review. *IOP Conference Series: Materials Science and Engineering*, *1003*(1), 012022. https://doi.org/10.1088/1757-899x/1003/1/012022
Ginting, R., Ishak, A., Malik, A. F., & Satrio, M. R. (2020). Product Development with Quality Function Deployment (QFD) : A Literature Review Product Development with Quality Function Deployment (QFD) : A Literature Review. *In IOP Conference Series: Materials Science and Engineering*, Vol. 1003, No. 1, 012022. https://doi.org/10.1088/1757-899X/1003/1/012022
Graves, J., Kuang, Y., & Zhu, M. (2022). Pendulum energy harvester with torsion spring mechanical energy storage regulator. *Sensors and Actuators A: Physical*, *339*, 113505. https://doi.org/10.1016/j.sna.2022.113505
Ilmiawan, F. A., & Zaki, S. A. (2023). Application of Flywheel Energy Storage on Generator-Set. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *105*(2), 78–87. https://doi.org/10.37934/arfmts.105.2.7887
Kouznetsova, A. V., Ryabkova, G. V., & Krasnova, T. I. (2021). The Technology Of Rotation Model Of Blended Learning Method In Technical Institutions. *European Proceedings of Social and Behavioural Sciences EpSBS*. https://doi.org/10.15405/epsbs.2021.09.02.150
Leavy, P. (2017). *Research Design* (1st ed.). The Guilford Press A Division of Guilford Publications, Inc. 370 Seventh Avenue, Suite 1200, New York, NY 10001.
Li, M., & Zhang, J. (2021). Integrating Kano Model, AHP, and QFD methods for new product development based on text mining, intuitionistic fuzzy sets, and customers satisfaction. *Mathematical Problems in Engineering*, *2021*. https://doi.org/10.1155/2021/2349716
Mahbubur Rashid, M., & Salam, S. M. (2024). Controlling the Variable Inertia of Flywheel: A Scientific Review. *Asian Journal of Electrical and Electronic Engineering*, *4*(1), 17–28. https://doi.org/10.69955/ajoeee.2024.v4i1.57
Osman, A. R., Sarkar, J. B., & Islam, S. (2017). Revisiting Student Satisfaction Through Servqual: Private Tertiary Education Perspective. *British Journal of Education*, *5*(11), 119–137.
Panneerselvam, S. (2021). *Quality concepts in Industrial systems using QFD (Quality Function Deployment) – Survey*. *January*. https://doi.org/10.14445/23499362/IJIE-V8I1P102
Patel, M., Pardhi, B., Chopara, S., & Pal, M. (2018). Lightweight Composite Materials for Automotive - A Review. *International Research Journal of Engineering and Technology*, *3*(11), 41–47.
Reimer, L., Kaluza, A., Cerdas, F., Meschke, J., Vietor, T., & Herrmann, C. (2020). Design of eco-efficient body parts for electric vehicles considering life cycle environmental information. *Sustainability (Switzerland)*, *12*(14). https://doi.org/10.3390/su12145838
Santoso, I., Rau, H., Choirun, A., Aprilianto, H. C., Lestari, K., A'yuniah, S., & Kusumaningtyas, O. W. (2024). Application of QFD in sustainable new product development in the agro-industrial sector: a systematic literature review. *International Journal of Sustainable Engineering*, *17*(1), 167–185. https://doi.org/10.1080/19397038.2024.2417016
Sharma, J. (2020). Quality function deployment: exploiting interrelationships for progressive prioritization. *TQM Journal*, *33*(3), 681–705. https://doi.org/10.1108/TQM-06-2020-0121
Shinde, A., Singh Rawat, K., Mahajan, R., Pardeshi, V., Kamanna, B., & Sheravi, S. (2017). Design and Analysis of Flywheel for Different Geometries and Materials. *Global Journal of Enterprise Information System*, *9*(1), 95. https://doi.org/10.18311/gjeis/2017/15872
Wazeer, A., Das, A., Abeykoon, C., Sinha, A., & Karmakar, A. (2023). Composites for electric vehicles and automotive sector: A review. *Green Energy and Intelligent Transportation*, *2*(1), 100043. https://doi.org/10.1016/j.geits.2022.100043
Wiyogo, W., Duling, J. R., & Debora, D. (2019). Quality Function Deployment Analysis for Improvement of Practicum on Mechanical Engineering Education University of Palangka Raya.

In 5th UPI International Conference on Technical and Vocational Education and Training (ICTVET 2018). Atlantis Press., *299*(49), 24–28. https://doi.org/10.2991/ictvet-18.2019.6

Xu, K., Guo, Y., Lei, G., & Zhu, J. (2023). A Review of Flywheel Energy Storage System Technologies. *Energies*, *16*(18). https://doi.org/10.3390/en16186462

Yang, W., Wang, Y., Li, Y., Wang, J., Cheng, T., & Wang, Z. L. (2019). Integrated flywheel and spiral spring triboelectric nanogenerator for improving energy harvesting of intermittent excitations/triggering. *Nano Energy*, *66*, 104104. https://doi.org/https://doi.org/10.1016/j.nanoen.2019.104104

Yu, Y., Wang, M., Zhang, R., Mi, Z., & Zheng, X. (2022). Power Coordinated Control and Parameter Analysis for Spiral Spring Energy Storage Systems Based on Backstepping Control Under Current Vector Orientation. *Frontiers in Energy Research*, *10*(July), 1–11. https://doi.org/10.3389/fenrg.2022.923264